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PRELIMINARY OBSERVATIONS ON VACUUM COOLING OF FRUITS AND VEGETABLES

By

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Introduction

The purpose of the present report is to give the results of two preliminary tests in cooling fruits and vegetables by the use of an experimental vacuum apparatus. The tests were made at Weatherly, Pennsylvania, in cooperation with the Croll-Reynolds Engineering Company, manufacturers of the vacuum apparatus.

In the first test, performed May 4, 1949, a small, steel cylindrical chamber of about three cubic feet capacity was employed. In the second test, on May 24, the capacity of the vacuum chamber was about 22 cubic feet. According to information received from the manufacturer, the vacuum is obtained by the use of steam vapor based upon the same principle of air entrainment upon which the aspirator works. In the apparatus used in these experiments steam is substituted for the stream of water used in the aspirator, and the vacuum is created by means of three separate steam jets used in series, each consisting in principle of a steam nozzle and venturi throat, with a condenser placed between each of the jets.

The reduction in temperature of vegetables obtained by the vacuum apparatus is based upon the cooling effect of vaporization. As the vacuum is drawn, water from the surface of the produce is evaporated and cooled until its vapor pressure is reduced approximately to that corresponding to the vacuum. The heat of vaporization depends upon the temperature at which the change of state occurs, and the temperature in turn is determined by the pressure. For example, at a pressure of 760 mm. mercury water vaporizes (boils) at 212° F., while at a pressure (or vacuum) of 4.5 mm. mercury water evaporates at 32° F. Therefore, other factors equal, the degree of cooling to which the commodities are subjected may be controlled by the amount of vacuum produced in the chamber.

Methods and Results

In the results reported in Table 1 the temperatures were taken manually with fruit thermometers. In determining spinach temperatures the thermometer was thrust down into the center of the bagged spinach. All readings with corn were taken in the cob after boring a fresh hole with an awl. The readings with asparagus were taken in the basal end of the cut stalks, and in celery by pushing the thermometer into the center of the stalk.

Except for one tomato fruit (out of eight tested) no tissue injury due to bursting was observed in any of the fruits or vegetables, which included spinach, lettuce, corn, asparagus, celery, tomatoes, and oranges. Some of the outer wrapper leaves of lettuce (test 13, Table 1) were watersoaked and frozen, but the inner leaves were unaffected. Tomatoes, oranges and spinach eaten on the same day, and celery, lettuce, corn and asparagus eaten on the following day showed no loss in quality because of the vacuum treatment.

In tests 1 and 2 (Table 1) nine out of twenty-four cellophane spinach bags burst, mostly at the seams, even though they had two perforations per bag. In later tests bag ripping was controlled to a great extent by adding additional perforations, and by slowing down the rate at which the vacuum was drawn and broken.

In most tests the loads in the chamber were small and it took about three to five minutes to reach the desired vacuum. However, to evacuate the chamber during the lettuce test (test 13, Table 1) required seventeen minutes to establish a vacuum of 4.0 mm. mercury. It took 8.5 minutes to prime a vacuum of 3.8 mm. in the corn test (test 11, Table 1), and twenty-three minutes to reach 4.0 mm. in a celery run (test 12, Table 1). At the completion of the vacuum period, air was admitted to the chambers and normal atmospheric pressure was attained in about one-half to three minutes. A slight to moderate amount of condensation was noted on the produce and containers upon return to normal pressure.

During the normal operations of spinach prepackaging the trimmed leaves are washed, then placed in large mesh bags, and centrifuged to get rid of excess water. In tests 7 and 8 (Table 1) spinach bagged wet (i.e., not centrifuged as in the usual procedure) was compared with "dry" spinach that had been processed in the customary manner. The purpose of this was to see if during the vacuum cooling the excess water could be evaporated. In this way it was hoped that possibly the operation of drying by centrifugation could be eliminated in the prepackaging of spinach. However, considerable water and ice remained in the bags after the vacuum treatment. For a similar purpose, test 9, (Table 1) bulk spinach in a large mesh bag was wetted down and placed in the vacuum chamber. The results were the same as in tests 7 and 8, that is, the spinach remained very wet.

The results in Table 2 were obtained by inserting thermocouples into bagged spinach in top, center and bottom layers of the carton. Readings were made by means of a potentiometer just before the vacuum was drawn, immediately after the chamber was opened, and fifteen minutes later. It should be noted that the rise in temperature observed after fifteen minutes was due largely to normal warming up caused by exposure to the temperature of the air.

In Table 3 and Figure 1 the changes in temperature of bagged spinach were obtained by thermocouples and potentiometer during the actual process of vacuum cooling by running the thermocouple wiring into the vacuum chamber through an opening that was sealed by a taped rubber stopper.

Discussion

As mentioned in the introduction, the temperature at which water vaporizes is determined by the pressure, the lower the pressure the lower the temperature. A comparison of tests 1 and 2 shows that the greater the amount of the vacuum to which bagged spinach was subjected the lower the temperature obtained, see Table 4.

The experiments indicate that leafy vegetables such as spinach and lettuce, having a large ratio of leaf surface area to volume, are cooled more rapidly and effectively (with less vacuum and time) than such vegetables as corn and asparagus, whose ratios of surface area to volume are smaller, see Table 5. It can be further noted, that there was very little cooling effect at the center of a tomato and orange, although it should be mentioned that these fruit were dry and that they might have been cooled more if they had been moistened first.

The tests reported here were run in two small experimental vacuum chambers and were exploratory in nature. The preliminary results appear to indicate that for certain types of vegetables, especially the leafy ones, vacuum cooling may hold considerable promise.

Table 1

Effect of Vacuum upon Temperatures of Various Vegetables

Test No.	Date	Commodity	Vacuum		Position of Produce	Temperature of Commodity (° F.)		Remarks
			Millimeters Mercury	Duration (Minutes)		Before Vacuum	After Vacuum	
1	5/4/49	Spinach, perforated carton of 12 cellophane (MSAT-86, 450 gauge) heat sealed prepackaged bags. Two perforations per bag.	5.0	5	-	80	39, 38	Four bags broken.
2	5/4/49	Spinach, perforated carton of 12 cellophane (MSAT-86, 450 gauge), heat-sealed, prepackaged bags. Two perforations per bag.	4.5	5	-	80	31, 33	Five bags broken.
3	5/4/49	Spinach, perforated carton of 12 cellophane (MSAT-86, 450 gauge), heat-sealed, prepackaged bags. Twelve perforations per bag.	4.5	5	-	78	32, 32	
4	5/24/49	Spinach, perforated carton of 12 cellophane (MSAT-86, 450 gauge), heat-sealed, prepackaged bags. Two perforations per bag.	4.5	5	-	79	32, 32	
5	5/24/49	Spinach, perforated carton of 12 cellophane (LSAT, 450), stapled, saddle labeled, prepackaged bags. Bags not perforated	4.4	5	Outer layer Inner layer	46 48,46	41, 38 42,39,38	One bag broken.
6	5/24/49	Spinach, perforated carton of 12 cellophane (LSAT, 450), stapled, saddle labeled, prepackaged bags. Four perforations per bag.	3.3	5	-	41,38, 36, 34, 42,39, 34, 34, 38	37, 32, 32, 31, 31	One bag broken

Table 1 (Continued)

Test No.	Date	Commodity	Vacuum: Millimeters Mercury	Vacuum: Duration (Minutes)	Position of Produce	Temperature of Commodity (° F.): Before Vacuum	Temperature of Commodity (° F.): After Vacuum	Remarks
7	5/24/49	Spinach, perforated carton of 12 cellophane (LSAT, 450), stapled, saddle labeled, prepackaged bags Four perforations per bag. Spinach bagged wet.	4.3 plus 3.3	5	Outer layer	79,59	32,31	Bags still wet.
				5	Inner layer	58,52	32	Ice in bags.
		Same as above - spinach bagged dry.	4.3 plus 3.3	5	Outer layer	78,75 72,68	30	
				5	Inner layer	52,60 71,60	32,31, 32	
8	5/24/49	Same as above spinach bagged wet.	3.3	5	Outer layer	73,78	33	Bags still wet.
					Inner layer	72,62	31,33	Ice in bags.
	5/24/49	Same as above - spinach bagged dry.	3.3	5	Outer layer	76,63	36	
					Inner layer	77.76	39.35	
9	5/24/49	Spinach. About 20 lbs. in bulk, in large mesh nylon bag. Spinach wet.	4.0	5	-	67	57 (?)	Spinach wet, considerable ice present.
10	5/24/49	Asparagus. Bundled and tied, not cellophane wrapped. Placed in open basin, after thorough wetting	3.3	10	-	62,65	36,36	Ice formed on tips
	5/24/49	Corn. Prepackaged tray, cellophane wrapped corn. Two perforations per tray.	3.3	10	-	57,60	36,35	

Table 1 (Continued)

Test No.	Date	Commodity	Vacuum: Millimeters Mercury	Vacuum: Duration (Minutes)	Position of Produce	Temperature of Commodity (° F.): Before Vacuum	Temperature of Commodity (° F.): After Vacuum	Remarks
11	5/24/49	Corn, prepackaged tray, cellophane wrapped corn. Two perforations per tray.	3.8	5	-	74,76, 75,76,75	39,41 36,36,39,41	
	5/24/49	Celery, Crate of 36 stalks.	3.8	5	-	60,62,62 61,67,68 66,63, 67	45,48, 49,44, 44,49	
12	5/24/49	Celery. Crate of 36 stalks.	4.0	5		41	33	
13	5/24/49	Lettuce. Crate of 60 heads Not cellophane wrapped.	4.0	5	Outer layer: a. Surface of heads	69,70	31	
					b. Center of heads	71,70	32	
					Inner layer: a. Surface of heads	66,65	31,32	
					b. Center of head	68,65	33,33	
	5/24/49	Lettuce. Crate of 60 heads. Heads cellophane wrapped (PBDS), no perforations, sealed with scotch tape.	4.0	5	Outer layer: a. Surface of head	75	35,34	
					b. Center of head	75	33,32	
14	5/4/49	Tomato fruit cellophane wrapped, perforated trays. Fruit dry.	4.5	5		73	67	One of eight burst.
		Orange fruit, unwrapped. Fruit dry.	4.5	5		75	72	

Table 2

Temperatures obtained by use of thermocouples in two cartons of prepackaged spinach.

Spinach, cellophane-wrapped (LSAT, 450), stapled, saddle label. Bags with four perforations. Vacuum 3.3 mm., and held for five minutes.

Position	Temperature - (°F.) Before Vacuum	Immediately After Vacuum	15 Minutes After Vacuum
Spinach in bottom layer bags.	65.6, 65.8, 65.9, 66.2	30.6, 31.1	32.1, 36.0
	Average: 65.9	Average: 30.9	Average: 34.1
Spinach in center layer bags.	64.8, 64.8, 59.9, 60.1, 63.9, 64.1 61.0, 61.1	30.0, 29.7, 29.6 29.7	33.8, 34.3, 34.3 34.4
	Average: 62.5	Average: 29.8	Average: 34.2
Spinach in top layer bags.	71.9, 72.0, 68.9 69.2	29.7, 28.8	32.9, 34.5
	Average: 70.5	Average: 29.3	Average: 33.7
Air in center of carton.	68.4, 68.7, 64.6, 64.8	28.0, 30.9	39.0, 33.4
	Average: 66.6	Average: 29.5	Average: 36.2
Outside Air	67.5, 69.0		
	Average: 68.3		

Table 3

Temperature Changes in Prepackaged Spinach Bags
During Vacuum Cooling at 3.3 mm. Hg. for Ten Minutes

(Spinach bags packed in perforated carton)

Temperature of outer bag of spinach	Time (Minutes)	Temperature of center bag of spinach	Time (Minutes)	Temperature of air in center of carton	Time (Minutes)	Temperature of air in vacuum Chamber	Time (Minutes)
64.6	Start	67.0	Start	69.2	Start	70.6	Start
65.3	1	59.6	1	58.3	2	62.3	1
41.0	3	34.5	3	39.9	4	51.7	2
30.1	6	32.0	6	31.0	6	42.3	4
29.6	7	27.6	8	30.2	8	35.2	6
28.6	9	26.6	10	31.5	10	34.5	9
27.8	12	25.7	12	28.7	12	34.7	10
26.8	14	24.6	15	27.8	15	35.0	14
26,8	16	25.0	16	28.0	17	35.2	16

Table 4

Effect of the Amount of Vacuum upon Temperature

Test No.	Commodity	Vacuum		Temperature of Commodity (° F.)	
		Millimeters Mercury	Duration (Minutes)	Before Vacuum	After Vacuum
1	Spinach	5.0	5	80	39
2	"	4.5	5	80	32

Table 5

Effect of Type of Fruit and Vegetable upon Temperature

Test No.	Commodity	Millimeters Mercury	Duration (Minutes)	Temperature of Commodity (° F.)	
				Before Vacuum	After Vacuum
2	Spinach	4.5	5	80	32
13	Lettuce	4.0	5	68	32
10	Asparagus	3.3	10	64	36
10	Corn	3.3	10	59	36
14	Tomato	4.5	5	73	67
14	Orange	4.5	5	75	72

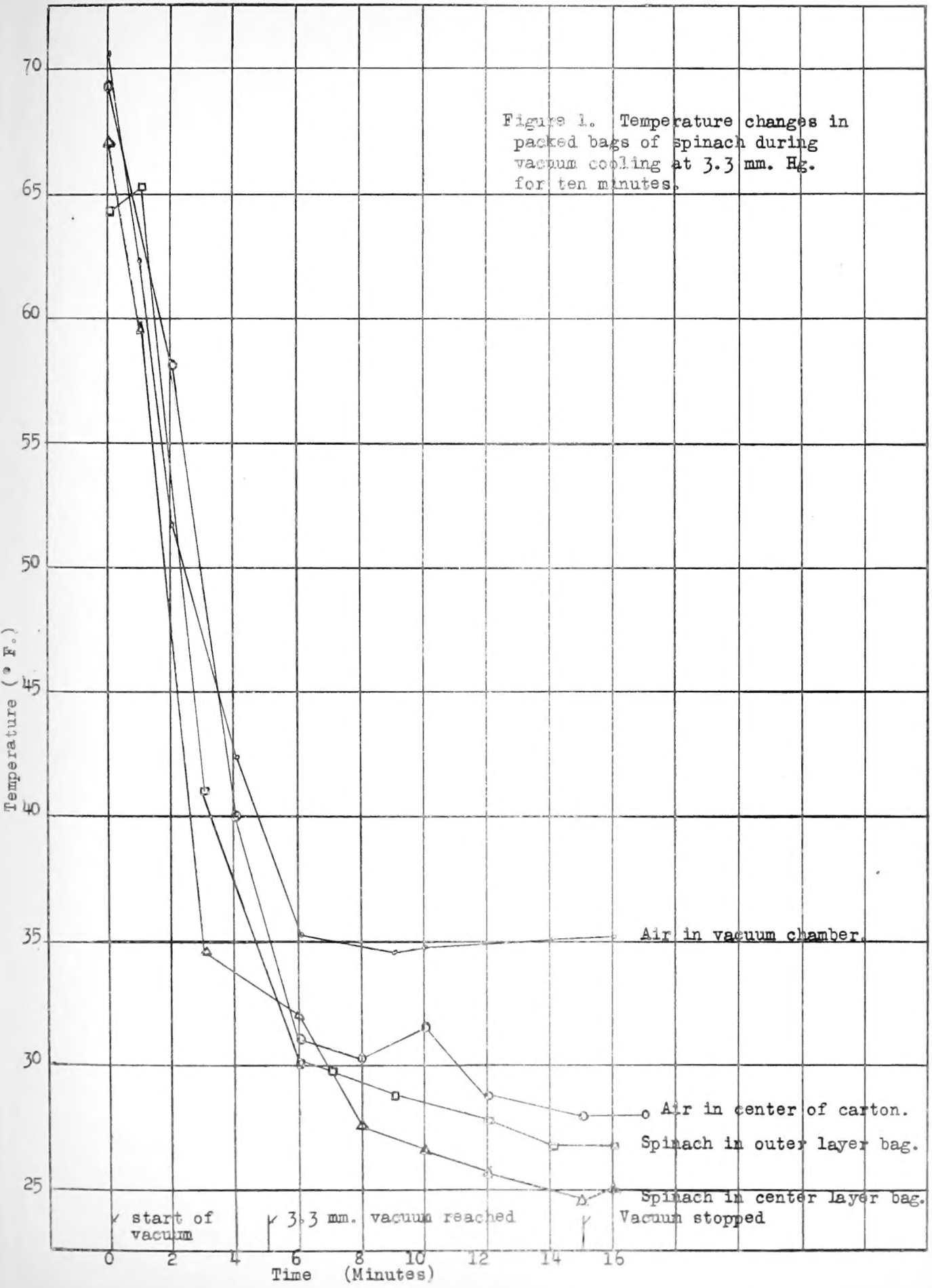

Figure 1. Temperature changes in packed bags of spinach during vacuum cooling at 3.3 mm. Hg. for ten minutes.